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# ELECTRICAL PROTECTION BY EFFECTIVE GROUNDING OF CABLE SHIELDS

Contents



## 1. General

1.1 This section provides REA Borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers telephone systems. It is written to present a technique for effectively grounding telephone cable shields.

1.2 Application of an effective grounding system is not recommended for every cable lead, in every company or all locations in the country. Implementation of an effective grounding system should be considered in locations where frequent damage due to electrical surges is experienced.

1.3 The original system was designed primarily for protection of telephone plant from the effects of ground potential rise (GPR) due to power system faults. Grounding telephone cable shields directs excessive voltages and currents induced on the shields to earth. This can often be achieved before these currents and voltages reach the location of plant or equipment requiring protection.

1.4 Application of an effective grounding system can increase the flow of current in the shielding circuit and provide better noise performance. It is essential that the shield be continuous with no opens or bonding problems if the maximum benefits of effective grounding are to be realized.

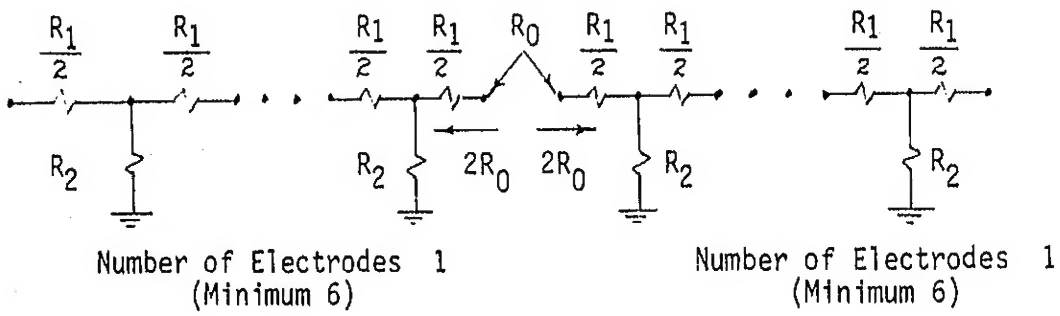
1.5 An effective grounding system can isolate damage by dissipating the current through multiple paths to ground along the cable shield. Due to the very high current in a lightning strike and the associated GPR it is not possible to protect the entire telephone plant from damage. As a result it is desirable to isolate damage from a near or direct lightning strike to the least plant length possible.

1.6 Obtaining a good ground is quite complex and can be expensive. Provision of a very good ground at every location (10 ohms or less resistance to earth) would be prohibitive from a cost standpoint. In parts of the country with very cold winters use of a short rod may result in freeze out due to a deep frost line during winter months.

## 2. Effective Grounding Theory

2.1 Effective grounding is based on the theory that multiple grounds along a cable shield (six or more in each direction from the test point) will provide a low value resistance to earth. A low resistance to earth is thus provided via multiple paths to earth for dissipation of high voltages and currents induced on cable shields.

2.2 A T-network equivalent to a typical cable grounding configuration is shown in Figure 1. $R_0$ equals the effective value of the grounding system, $R_1$ the resistance of the strand and/or cable shield resistance between ground electrodes, and $R_2$ the resistance of the individual ground electrode.




Typical Effective Grounding Configuration

FIGURE 1

2.21 The effective ground resistance ($R_O$) may be calculated by the equation:

$$R_0 = 0.5\sqrt{0.25R_1^2 + (R_1)(R_2)} \text{ ohms}$$

Where:

$R_O$ = Effective Resistance to earth in ohms

$R_1$ = Strand and/or cable shield resistance between electrodes in ohms

$R_2$ = Resistance to earth of individual electrode in ohms

2.22 For an example, assume a 25-pair 24-gauge filled buried cable with a 10 mil copper shield, 2.4 ohms/kilometer (0.73 ohms/kilofoot). If there are six ground electrodes spaced 685.8 meters in each direction, each with a resistance to earth of 250 ohms, the effective resistance to earth will be 10.0 ohms.

2.23 As an example of the effect from different shielding materials consider the same conditions shown in Paragraph 2.22 except the cable shield which is 6 mil copper-steel 6 ohms/kilometer (1.83 ohms/kilofoot). The effective resistance to earth will be 16.1 ohms.

2.24 From a protection consideration, it would be desirable to have the earth electrodes spaced closer together, perhaps every 304.8 meters (1 kilofoot) but this is not practical in most buried cable plant. It is worth considering in aerial plant for the lower the value of effective resistance to earth the better the overall system will perform.

2.3 The engineer will find it desirable on occasion to determine the maximum earth electrode resistance which, for example, will result in a 10 ohm effective resistance to earth. This may be calculated by the equation:

$$R_2 = \frac{4R_0^2 - 0.25R_1^2}{R_1} \text{ ohms}$$

Where:

$R_2$ = Resistance to earth of individual electrode

$R_O$ = Objective effective resistance to earth

$R_1$ = Strand and/or cable resistance between electrodes

2.4 At a point where the shield continuity is broken (open shield) there will be six earth electrodes in only one direction along the shield. Effective earth resistance at that point becomes:

$$2R_0 = \sqrt{0.25R_1^2 + (R_1)(R_2)} \text{ ohms}$$

Where:

$R_O$ = Effective resistance to earth

$R_1$ = Strand and/or cable resistance between electrodes

$R_2$ = Resistance to earth of individual electrode

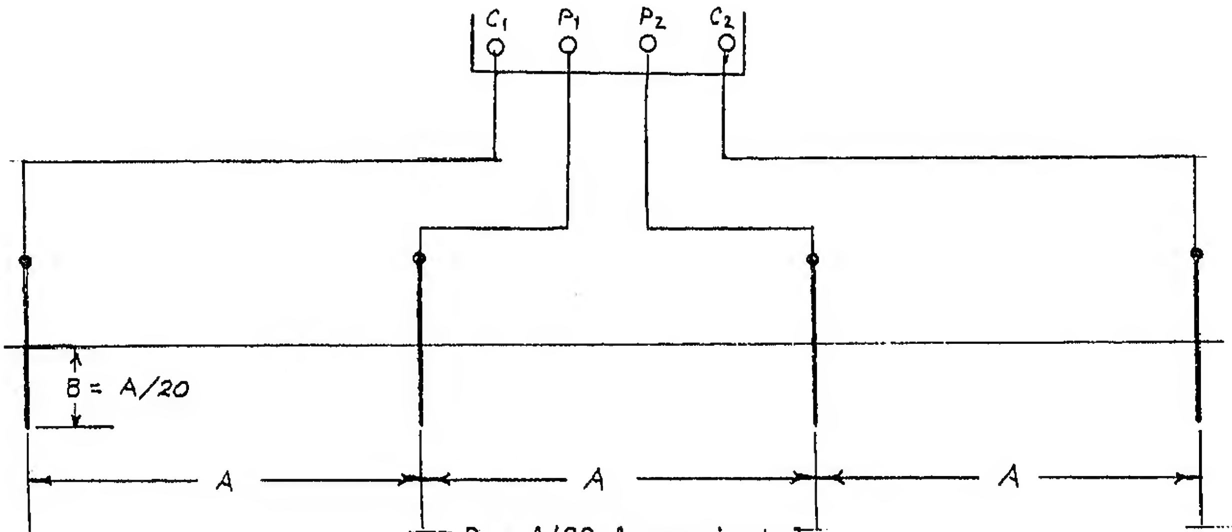
3. Earth Resistivity ($\rho$)

3.1 Adequate design of an effective ground system may best be accomplished by determining the earth resistivity in meter-ohms at each proposed earth electrode location. Earth resistivity can vary greatly in any area so it is not a good idea to measure at a few scattered locations and assume all other points are in the same range.

3.2 An earth resistance tester has the connections shown in Figure 2. The distance between the probes (A) is the depth electrode for which the earth resistivity is measured. Terminals $C_1$ and $C_2$ are connected to the two outer probes as shown and terminals $P_1$ and $P_2$ to the inner probes. The depth of the test probes (B) should be approximately 1/20A as shown in Table I.

Table I

| A | | B | |
|---|---|---|---|
| Feet | Meters | Inches | Centimeters |
| 5 | 0.1524 | 3 | 7.62 |
| 10 | 0.3048 | 6 | 15.24 |
| 15 | 0.4572 | 9 | 22.86 |
| 20 | 0.6096 | 12 | 30.48 |




B = A/20 Approximately

Measurement of Earth Resistivity ($\rho$)

FIGURE 2

3.21 Read the resistance value of the earth tester after meter has been nulled if of null balance type. This resistance is usually a dial setting times a multiplier. Some new instruments the value may be read directly from dials.

3.22 Calculate earth resistivity from this resistance (R) by the equation:

When meter-ohms desired $\rho = 6.28AR$ where A is in meters
When centimeter-ohms desired $\rho = 6.28AR$ where A is in centimeters
or
When meter-ohms desired $\rho = 1.9151AR$ where A is in feet
When centimeter-ohms desired $\rho = 191.51AR$ where A is in feet

## 4. Earth Electrode Resistance

4.1 Once the earth resistivity at a location has been determined the resistance of an earth electrode can be calculated. As will be shown later in the design portion of this section it is not necessary to complete this calculation at the individual locations.

4.2 Single Electrode: Resistance to earth for an earth electrode of given size can be calculated for a known value of earth resistivity by the equation:

$$R_2 = \frac{\rho}{2\pi \ell} \left(\log_e \frac{4\ell}{a} - 1\right) \text{ ohms}$$

Where:

$R_2$ = Earth Electrode Resistance to earth

$\rho$ = Earth resistivity in meter-ohms

$\ell$ = length of electrode in meters

a = Radius of electrode in meters

Or may be measured directly, when the electrode is in place, using the techniques in Paragraph 4.1 of TE&CM 802.

4.21 Since the size of ground rods used in the telephone industry today is usually given in feet and inches the equation can be adjusted as follows:

$$R_2 = \frac{\rho}{1.9151\ell} \left(\log_e \frac{96\ell}{a} - 1\right) \text{ ohms}$$

Where:

$R_2$ = Earth Electrode Resistance to earth

$\rho$ = Earth resistivity in meter-ohms

$\ell$ = Length of electrode in feet

a = Diameter of electrode in inches

4.22 Chart 1 has been developed with the above formulas for 1.59 cm (5/8") diameter ground rods of various lengths. The resistance to earth can be read for any value of earth resistivity from this chart when necessary.

4.3 Multiple Electrodes: There will be cases where the resistance to earth of single electrode is too high to have an effective earth resistance equal to or lower than the objective. It then becomes necessary to consider the use of two or more parallel electrodes at some locations. There are three possible conditions relative to parallel electrodes: 1. Distance between the electrodes is equal to the length of the electrodes., 2. Distance between the electrodes is greater than the length of the electrodes, and 3. Distance between the electrodes is less than the length of electrodes. These different states result in two equations for calculation of the multiple electrodes parallel resistance to earth (Rp).

4.31 When the distance between parallel earth electrodes is equal to or greater than the length of the electrodes and measurements are in meters the parallel resistance to earth should be calculated by the following equation:

$$d \geq \ell$$

$$Rp = \frac{1}{n} (R_2 + \frac{\rho}{\pi d} ( 1/2 + 1/3 \cdot \cdot \cdot 1/n) \text{ ohms}$$

Where:

Rp = Parallel resistance to earth of electrodes in ohms

n = Number of electrodes

$R_2$ = Earth electrode resistance to earth in ohms

$\rho$ = Earth resistivity in meter-ohms

$\pi$ = 3.14

d = Distance between earth electrodes in meters

$\ell$ = length of earth electrodes in meters

4.32 The following equation should be used to calculate parallel earth electrode resistance to earth where the distance between the electrodes equal to or greater than the electrodes lengths and all measurements are in feet.

$$d \geq \ell$$

$$R_p = \frac{1}{n} (R_2 + \frac{\rho}{.9576d} (½ + 1/3 \cdot \cdot \cdot \frac{1}{n}) \text{ ohms}$$

Where:

$R_p$ = Parallel resistance to earth of earth electrodes in ohms.

$n$ = Number of electrodes

$R_2$ = Earth electrode resistance to earth in ohms

$\rho$ = Earth resistivity in meter-ohms

$d$ = Distance between earth electrodes in feet

$\ell$ = Length of earth electrodes in feet

4.33 Where the distance between parallel earth electrodes is less than the length of the electrodes is necessary to calculate first the mutual resistance ($R_m$) between two parallel electrodes at the specified spacing.

4.331 When measurements are in meters mutual resistance may be calculated by the following equation:

$$d<\ell$$

$$R_m = \frac{\rho}{2\pi\ell}\left(\log_e \frac{4\ell}{d} - 1\right) \text{ ohms}$$

Where:

$R_m$ = Mutual resistance between earth electrodes in ohms

$\rho$ = Earth resistivity in meter-ohms

$2\pi$ = 6.28

$\ell$ = Length of earth electrode in meters

$d$ = Distance between earth electrodes in meters

4.332 Mutual resistance may be calculated by the following equation when measurements are in feet:

$$d<\ell$$

$$R_m = \frac{\rho}{1.9151\ell}\left(\log_e \frac{4\ell}{d} - 1\right) \text{ ohms}$$

Where:

$R_m$ = Mutual resistance between earth electrodes in ohms

$\rho$ = Earth resistivity in meter-ohms

$\ell$ = Length of earth electrode in feet

$d$ = Distance between earth electrodes in feet

4.333 When the distance between parallel earth electrodes is less than the length of the electrodes the parallel resistance should be calculated by the following equation:

$$d<\ell$$

$$R_p = \frac{1}{n} (R_2 + (n-1)\ R_m) \text{ ohms}$$

Where:

$R_p$ = Parallel resistance to earth of earth electrode in ohms.

$n$ = Number of electrodes

$R_2$ = Earth electrode resistance to earth in ohms

$R_m$ = Mutual resistance between earth electrodes in ohms (From Paragraph 4.331 or 4.332)

4.4 Charts 2, 3, and 4 have been developed with the above formulas for 1.59 cm (5/8") diameter ground rods of various lengths in multiples of 2, 3, and 4 rods; respectively. The resistance to earth can be found for any value of earth resistivity form these charts.

4.5 Since $R_2$ (Ground electrode resistance to earth) can be calculated by the equation in Paragraphs 4.2 and 4.21 the design procedure for effective ground can be simplified by combining with the equation in Paragraph 2.21 for effective resistance.

4.51 Where measurements are in meters the resulting equation is:

$$R_o = 0.5 \sqrt{0.25\ (R_1)^2 + R_1\ (\frac{\rho}{2\pi\ell}\ (\log_e \frac{4\ell}{a} - 1))} \text{ ohms}$$

Where:

$R_o$ = Effective Resistance to earth in ohms

$R_1$ = Strand and/or cable shield resistance between electrodes in ohms

$\rho$ = Earth resistivity in meter ohms

$2\pi$ = 6.28

$\ell$ = Length of electrode in meters

a = Radius of electrode in meters

4.52 Where measurements are in feet the resulting equation is:

$$R_o = 0.5 \sqrt{0.25R_1^{\ 2} + R_1 \left(\frac{\rho}{1.9151\ell} \left(\log_e \frac{96\ell}{a} - 1\right)\right)} \quad \text{ohms}$$

Where:

$R_o$ = Effective Resistance to earth in ohms

$R_1$ = Strand and/or Cable Shield resistance between electrodes in ohms

$\rho$ = Earth resistivity in ohms

$\ell$ = Length of electrode in feet

a = Diameter of electrode in inches

4.53 This equation can be set to find the required value of earth resistivity from a given value of resistance between electrodes for any desired value of effective resistance to earth.

4.531 Where measurements are in meters:

$$\rho = \frac{(4R_o^{\ 2} - 0.25R_1^{\ 2})\ (2\pi\ell)}{R_1\ (\log_e \frac{4\ell}{a} - 1)} \quad \text{meter ohms}$$

Where:

$R_1$ = Strand and/or cable shield resistance between electrodes in ohms

$\rho$ = Earth resistivity in meter ohms

$R_o$ = Objective effective resistance to earth in ohms

$2\pi = 6.28$

$\ell$ = Length of electrode in meters

a = Radius of electrode in meters

4.532 Where measurements are in feet:

$$\rho = \frac{(4R_o^2 - 0.25R_1^2)\ (1.9151\ell)}{R_1\ (\log_e \frac{96}{a} - 1)} \text{ meter ohms}$$

Where:

$R_1$ = Strand and/or cable shield resistance between electrodes in ohms

$\rho$ = Earth resistivity in meter-ohms

$R_o$ = Objective effective resistance to earth in ohms

$\ell$ = Length of electrode in feet

a = Diameter of electrode in inches

4.56 Chart 5 has been developed with these formulas. Strand and/or shield resistance between electrodes can be found for any value of earth resistivity which will result in a 10 ohm effective resistance to earth. To obtain the curve for effective resistance to earth from the end of a cable (six electrodes in one direction) $R_o$ was set to 5 ohms to obtain the desired $2R_o$ equals 10 ohms.

5. Design of Effective Grounding System

5.1 Objective Effective Ground Resistance: Resistance to earth at any point along a cable with an effective grounding system should be 10 ohms or less where there are a minimum of six electrode points in each direction from the point of measurement. As shown in Paragraph 2.22 if the resistance to earth of the twelve electrodes adjacent to the end of the cable is the same value the resistance to earth at the end of the cable will be twice that found at the midpoint of the twelve electrodes. Effort should be directed toward obtaining lower resistance to earth for the individual electrodes near the end of the cable. Ideally, the resistance to earth at the end of the cable should be 10 ohms or less, but this is not always practical. (See Paragraph 5.35).

5.2 General: Three items of information are needed for the design of an effective grounding system, resistance of the strand and/or cable shield per unit length, distance between earth electrode locations, and the measured earth resistivity at each proposed electrode location.

5.21 Depending on whether the telephone plant is aerial or buried there are two basic approaches to the design of an effective grounding system. With aerial plant there is no problem with spacing between earth electrodes since the plant is continuously accessible. Thus the basic design consideration with aerial plant is the determination of what spacing will, with the given strand and cable shield resistance and the measured earth resistivity, provide a 10 ohm effective resistance to earth. Where the cable plant is buried the spacing between electrodes is determined by where the cable must be accessed for location of loading coils or carrier repeaters. Here then the basic design consideration is the determination of what earth electrode resistance will, with the given cable shield resistance and measured earth resistivity, provide a 10 ohm effective resistance to earth.

5.22 Regardless of whether plant is aerial or buried some data relative to the earth resistivity along the route is necessary as a starting point. Measurements of earth resistivity at the ten foot depth at several points along the route should be made to establish a profile. Measurements at each loading or repeater point along the route should provide adequate information.

5.23 As a general rule earth electrode spacing should not exceed 609.4 meters (2000 feet). With H88 loading this may be exceeded by about two percent since to insure relatively even spacing between electrodes, it is recommended the distance between two adjacent loading points be divided into three equal segments. The distance between H88 loading coils can exceed 1828.8 meters (6000 feet) by about two percent. One exception is made to this rule when D66 loading is used. Here the distance between loading coils is 1371.6 meters (4500 feet). Dividing this into three 457.2 meters (1500 foot) in average areas could result in an excessive number of electrodes over those necessary to meet effective ground objectives. While the lower values of effective resistance to earth might be desirable the added costs cannot be justified. The distance between two adjacent loading coils should be divided into two equal segments of approximately 685.8 meters (2250 feet) plus three percent to allow for load spacing deviations. These maximum distances apply more to buried than to aerial plant. Shorter spacings of the earth electrodes are preferred since a more efficient effective grounding system will result. Induced voltages can be drained from the cable shield in shorter distances and if lightning damage does occur, it can be isolated in shorter lengths of cable.

5.24 An earth electrode 1.59 cm x 3.048 meters (5/8" x 10') appears to be best for the average effective grounding system design. Shorter electrodes demonstrate a greater variation in resistance to

earth during periods of cold weather. This is especially severe in areas where the frost line approaches 0.91 to 1.22 meters (3 to 4 feet) where freeze out can occur. They also are more subject to variations during dry weather cycles. For these reasons design of an effective grounding system should initially be based on single 1.59 cm x 3.048 meters (5/8" x 10') earth electrodes.

5.25 At locations where a lower resistance to earth is required than can be obtained with a single 10 foot (3.048 meter) electrode there are two alternatives available. A second electrode can be placed in parallel to the first or using sectionalized electrodes the first electrode can be driven deeper into the earth. The preferred solution will be indicated by existing conditions. In some areas the deep electrode may be impractical due to subsurface rock strata. There may also be areas of multiple strata earth where a long electrode will result in a great reduction of the resistance to earth. Measurements of earth resistivity will determine these locations. Where multiple electrodes are to be used the spacing between electrodes should equal or exceed the electrode length. If shorter spacing is used they are in the influence of each other and the parallel resistance to earth is higher. Greater separation does not result in a great reduction in resistance to earth below that achieved with spacing equal to electrode length.

5.26 The basic design is accomplished by using average values of earth resistivity for the six electrode locations in each direction from a point. While this does not provide the precise value of effective resistance to earth the resulting error is small. Obtaining the precise value would entail the development and solution of twelve simultaneous equations based on the current flowing in each node.

5.27 Branch cables, for design purposes, are treated as an extension of the main cable from the point of departure. Following completion of the first phase of the design procedure in Paragraph 5.3 or 5.4 the branch cables are considered. The first twelve electrode locations to be averaged are the first six along the branch cable and the first six along the main cable toward the office from the junction point. Then proceed toward the end of the branch cable as discussed in Paragraph 5.3 or 5.4. This will result in a slightly higher calculated effective resistance to earth then will be measured when within six electrode locations from a junction point.

5.28 Connections to the multi-grounded neutral (MGN) of the power system and earth electrodes at station locations are not included in design calculations. These connections will result in a measured effective resistance to earth lower than the calculated design value.

5.29 Changes in cable size along the route are handled by averaging the resistances between electrodes to derive a new value. For example: The cable has a resistance between electrodes of one ohm and is connected to a cable having one and a half ohms resistance between electrodes. When the first length of higher shield resistance enters

a group of twelve electrode locations the new resistance between electrodes is 1.04 ohms. The averages will increase to 1.08, 1.13, 1.17, 1.21, 1.25, 1.29, 1.33, 1.38, 1.42, 1.46 and finally 1.5 when all twelve electrodes being averaged are beyond the point the cable size changed.

5.3 Aerial Cable Plant: Assuming earth resistivity measurements have been completed as discussed in Paragraph 5.22 average the recorded values along the route. Using the equation shown in Paragraph 4.61 calculate the spacing that will provide a 10 ohm effective resistance to earth with the calculated average earth resistivity and given strand and shield resistance per unit length.

5.31 Determine on a map or in the field the location of each earth electrode based on the spacing found. Some adjustments will be necessary to locate all electrodes at pole locations. Measure the earth resistivity at each location to the 3.048 meter (10 foot) depth. (See Paragraph 3.0 for a discussion of earth resistivity measurement.) When a location is where the measured value of earth resistivity is many times higher than at adjacent locations measurements should be made one span in both directions. If lower values are found the electrode location should be shifted. Factors such as earth fills can create pockets of high earth resistivity which can be avoided by moving the electrode location a short distance in either direction.

5.32 Average the recorded values of earth resistivity for the first twelve earth electrode locations starting at the office end of the route. With this average value use Chart 5 to determine the maximum strand and shield resistance between electrodes that will produce a 10 ohm effective ground. If this value is equal to or greater than the given strand and shield resistance for this section of the route objectives will be met and design can proceed. Should the value be lower than the given strand and shield resistance it will be necessary to reduce the resistance of one or more of the electrodes. Find the location with the highest value of earth resistivity. Determine whether a parallel electrode or additional section on the proposed electrode is preferred. Then determine the resistance to earth of the new electrode from Chart 1, if longer electrode is to be placed, or Chart 2, if a parallel electrode is to be placed. Since this new electrode is the equivalent of a 3.048 meter (10 foot) electrode of the same resistance to earth at x ohms earth resistivity determine the equivalent value of earth resistivity from Chart 1. Using this new value of earth resistivity for the electrode location, average the earth resistivity for the twelve locations again and from Chart 5 determine if the objectives are now met. If not, find the location of the remaining highest earth resistivity and proceed as before. This is done until the objectives are met.

5.33 Drop the earth resistivity value of the first electrode out of the office and add that of the thirteenth. Average the values of earth resistivity for these twelve electrodes and proceed as discussed in Paragraph 5.32. Remember, if a longer or parallel electrode was required in the previous calculation that the equivalent earth resistivity will be used to find the new average.

5.34 Proceed one electrode at a time until the last electrode along the cable has been averaged in a group of twelve. If the cable route involved is a trunk route, this completes the design. Since the low office ground value will predominate over the first six electrodes the effective ground should meet the 10 ohm objective end to end.

5.35 Where the cable is not a trunk cable one end will not terminate at an office ground. When there are only six electrodes in one direction from a point it has been shown in Paragraph 2.5 that the resistance to earth from that point is two times the value of effective resistance to earth with six electrodes in both directions when all other factors are the same. It has also been shown an effective ground system design can be accomplished by averaged measured and equivalent values of earth resistivity (Paragraph 5.32). These same principles can be applied to designing the system at the end of the cable.

5.351 Average the recorded values of earth resistivity for the last six electrode locations along the cable. From Chart 5 determine for the given value of strand and shield resistance what average earth resistivity value will result in a 10 ohm value for $2R_o$. If this value of average earth resistivity is higher than the calculated value form recorded measurements the 10 ohm objective will be met and the design has been completed.

5.352 When the calculated average value of earth resistivity is higher than that found in Chart 5 it will be necessary to consider multiple or longer electrodes at some locations. The six recorded earth resistivity values should be studied. It should be remembered that most efficient effective grounding will result when the resistance to earth of the last electrode is the lowest of the last six locations. If one of the six values is very high (more than twice that of the next lower value) it should be considered first. Determine whether the preferred solution at that location is a parallel or longer electrode. Determine the resistance to earth of the new electrode from Chart 1, if deeper electrode is to be placed, or Chart 2, if a parallel electrode is to be placed. Using this resistance to earth value determine from Chart 1 the equivalent earth resistivity for a single 3.048 meter (10 foot) electrode of the same resistance to earth. With this new earth resistivity value for the electrode location again average the earth resistivity values and compare to the objective value from Chart 5 to determine if the objectives will be met. Where all six values of earth resistivity are essentially the same (no value more than twice that of the next lower value) the electrode improvement should be started with the one furthest from the office and working from there, one electrode at a time back toward the office until objectives are met.

5.36 Branch cables and different cable sizes along the route are handled as discussed in Paragraph 5.2.

5.4 Buried Cable Plant: Design of an effective grounding system for buried cable plant is different than for aerial cable plant. The flexibility of varied spacing to achieve objective effective resistance to earth does not exist since the buried cable cannot be accessed at any point along the length as can aerial cable. An effective grounding system must conform to the loading coil or carrier repeater spacing with a minimum of additional points of access to achieve the desired goal. Recommended spacing for buried cable plant are 685.8 meters (2250 feet) with D66 loaded cable and 609.4 meters (2000 feet) (609.4 meters) with H88 loaded cable. There may be some areas of extremely high earth resistivity where a spacing of 457.2 meters (1500 feet) might be justified with both loading systems. Where such areas are found economic studies should be made to determine the best course of action.

5.41 The initial step is to determine on a map or in the field the location of each earth electrode based on the loading system being used. Measure the earth resistivity at each location to the 3.048 meter (10 foot) depth. Where earth resistivity is high (more than two times the average value) it should also be measured to the 6.096 meter (20 foot) depth. (See Paragraph 3.0 for a discussion of earth resistivity measurement).

5.42 Average the recorded values of earth resistivity for the first twelve earth electrode locations starting at the office end of the route. Use Chart 5 (depending on unit of measurement) to determine from the given shield resistance per kilofoot or meter the average earth resistivity necessary to meet a 10 ohm effective resistance to earth if this value is equal to or greater than the calculated earth resistivity for the spacings objectives will be met and design can proceed to next step. Should the value be lower than the calculated earth resistivity it will be necessary to reduce the resistance of one or more of the earth electrodes. Find the location with the highest value of earth resistivity and determine whether a parallel electrode or an additional section on the proposed electrode is preferred. Then determine the resistance to earth of the new electrode from Chart 1, if longer electrode is to be placed, or Chart 2, if a parallel electrode is to be placed. Since this new electrode is the equivalent of a 3.048 meter (10 foot) electrode having the same resistance to earth with x ohms earth resistivity determine the equivalent value of earth resistivity from Chart 1. Using this new equivalent value of earth resistivity for the electrode location, average the earth resistivity again for the twelve locations. Compare the new average earth resistivity with the objective earth resitivity found on Chart 5 above to determine if the 10 ohm objective effective resistance to earth will be met. If the objective is still lower than the calculated average value find the next highest value of earth resistivity. Proceed as before with either a parallel or longer electrode. Continue this procedure until objectives are met.

5.43 Drop the earth resistivity value of the first electrode out of the office and add that of the thirteenth. Average the values of earth resistivity for these twelve electrodes and proceed as discussed in Paragraph 5.42. Remember, if a longer or parallel electrode was required at any of these points in the first computation, that the equivalent earth resistivity value will be used for that location during these calculations.

5.44 Proceed one electrode at a time until the last electrode along the cable has been averaged in a group of twelve. If the cable route is a trunk route this completes the design. Since the low office ground will predominate over the average value of the first six electrodes the effective resistance to ground should meet the 10 ohm objective end to end.

5.45 Where the cable is along a subscriber cable route the last six electrode locations will be handled as discussed in Paragraph 5.35 for aerial cable plant. When there are only six electrodes in one direction from a point it has been shown in Paragraph 2.5 that the resistance to earth from that point is two times the value of effective resistance to earth with six electrodes in both directions when all other factors are the same. It has also been shown an effective grounding system design can be accomplished by average measured and equivalent values of earth resistivity (Paragraph 5.43). These same principles can be applied to designing the system at the end of the cable.

5.451 Average the recorded values of earth resistivity for the last six electrode locations along the cable. From Chart 5 determine for the given value of shield resistance what average earth resistivity value will produce a 10 ohm value of 2 $R_o$. If this value of average earth resistivity is higher than the average value calculated from recorded measurements the 10 ohm objective will be met and the design has been completed.

5.452 Where the calculated average value of earth resistivity is higher than that found in Chart 5 it will be necessary to consider multiple or longer electrodes at some locations. The six recorded earth resistivity values should be studied. It should be remembered that most efficient effective grounding will result when the resistance to earth of the last electrode is the lowest of the last six locations. If one of the six values is very high (more than twice that of the next lower value) it should be considered first. Determine whether the preferred solution at that location is a parallel or longer electrode. Determine the resistance to earth of the new electrode from Chart 1, if deeper electrode to be placed, or Chart 2, if a parallel electrode is to be placed. Using this resistance to earth value determine from Chart 1 the equivalent earth resistivity for a single 10 foot (3.048 meter) electrode of the same resistance to earth. With this new earth resistivity value for the electrode location again average the six earth resistivity values and compare to the objective value from Chart 5 to determine if the objectives

have been met. Where all six values of earth resistivity are essentially the same (no value more than twice that of the next lower value) the electrode improvement should be started with the one furtherest from the office and, working from there, one electrode at a time back toward the office until objectives are met.

5.46 Branch cables and different cable sizes along the route are handled as discussed in Paragraph 5.2

6. Example of Effective Grounding Design

6.1 Figure 1 shows the details of a cable route for which an effective grounding system is to be designed. Since this is buried cable, the spacing between electrodes is controlled by the loading spacing. Results of earth resistivity measurements are shown on the schematic.

6.2 Set up a work sheet as shown in Example 1 and list by number the electrode locations, starting at the office end. Also enter the measured earth resistivity at each of these locations.

6.21 Start the design between the 6th and 7th electrode location. First average the shield resistance between earth electrodes over the length of the first twelve electrodes. Since the entire length is 50-24 cable the average is 1.98 ohms. From Chart 5 the objective average earth resistivity value (605 meter-ohms) may be determined for a 1.98 ohm resistance between electrodes and a 10 ohm objective effective resistance to earth ($R_o$ = 10 ohms). Next average the recorded measured values of earth resistivity for the twelve electrode locations. Since the 460 meter-ohms average value is lower than the 605 meter-ohms objective value for this location the effective grounding objectives will be met.

6.22 Design now moves to the location between the 7th and 8th electrode. Again, the shield resistance between electrodes are averaged. However, there is one section 25-24 cable added at the end fartherest from the office and the first section nearest the office is dropped. The new average shield resistance is 2.02 ohms. A new value of objective earth resistivity of 600 meter-ohms is found for this value of $R_1$ from Chart 5. Recorded values of measured earth resistivity for the twelve electrodes (2 thru 13) are averaged and the value of 467 meter-ohms compared to the objective earth resistivity for this location. Again it is lower so effective grounding objectives will be met.

6.23 This same procedure is followed between the 8th and 9th electrode and successively along the cable until the point is reached where there are six electrode locations remaining to the end of the cable. The point in the example is between locations 14 and 15.

6.231 In the example the average measured values of earth resistivity at all locations were lower than objective values. There was thus no need for further design work at these locations.

6.232 Should any of the average values of earth resistivity have been higher than the objective values it would have been necessary to use multiple or longer electrodes at one or more locations to provide a lower equivalent earth resistivity. Procedure to be followed is identical to that discussed in Paragraph 6.

6.3 Design for the six electrode locations farthest from the office should be started from the end of the cable. First average the shield resistance between electrodes over the length of the last six electrodes along the cable. Since the entire length is 25-24 cable the average is 2.48 ohms. From Chart 5 the objective average earth resistivity value (120 meter-ohms) may be determined for a 2.48 resistance between electrodes and 10 ohm objective effective resistance to earth ($2R_o$ = 10 ohms). Next average the recorded measured values of earth resistivity for the six electrode locations. Since the 493 meter-ohms average is higher than the 120 meter-ohms objective value use of multiple or longer electrodes should be considered.

6.31 The first decision is whether to use multiple or longer electrodes. Most obvious is whether the terrain is the type where long sectional rods may be driven. If not the only alternative is to place multiple electrodes. Where the longer rods may be driven the value of measured earth resistivity to each depth will usually determine the best method. When the earth resistivity at the lower depth is larger the lowest electrode resistance to earth will be obtained with multiple electrodes in parallel. Where earth resistivity is uniform at the depths measured the electrode resistance to earth will be approximately the same for multiple or longer configurations so either may be used. When the lower depth measured has the lowest value of earth resistivity then the longer electrode will have the lowest resistance to earth.

6.32 For Example 1 a uniform earth resistivity has been assumed for both depths, 3.048 and 6.096 meters (10 and 20 feet). Highest earth resistivity is at location 15 (650 meter-ohms). Using Chart 2 two electrodes with 650 meter-ohms will have a resistance to earth of 125 ohms. From Chart 1 it is found that a single 3.048 meter (10 foot) electrode would have 125 ohms resistance to earth if earth resistivity is 380 meter-ohms. This is the equivalent value to be entered and the earth resistivity values for the six locations are again averaged. The resulting 448 meter-ohms is higher than the 120 meter-ohms objective so the next highest value at location 16 (640 meter-ohms) is designed for multiple electrodes in the same manner.

6.33 After determining the equivalent earth resistivity values for all six electrode locations with two electrodes the resulting average earth resistivity is 288 meter-ohms. This is higher than the 120 meter-ohms objective and from Charts 1 and 6 results in an effective

resistance to earth of 15.4 ohms. For a shield resistance between electrodes of 2.48 ohms and earth resistivity of 288 meter-ohms $R_o = 7.7$ ohms. With six electrodes in one direction only the effective resistance equals $2R_o$ or 15.4 ohms. The effective resistance to earth with single electrodes was 20.2 ohms.

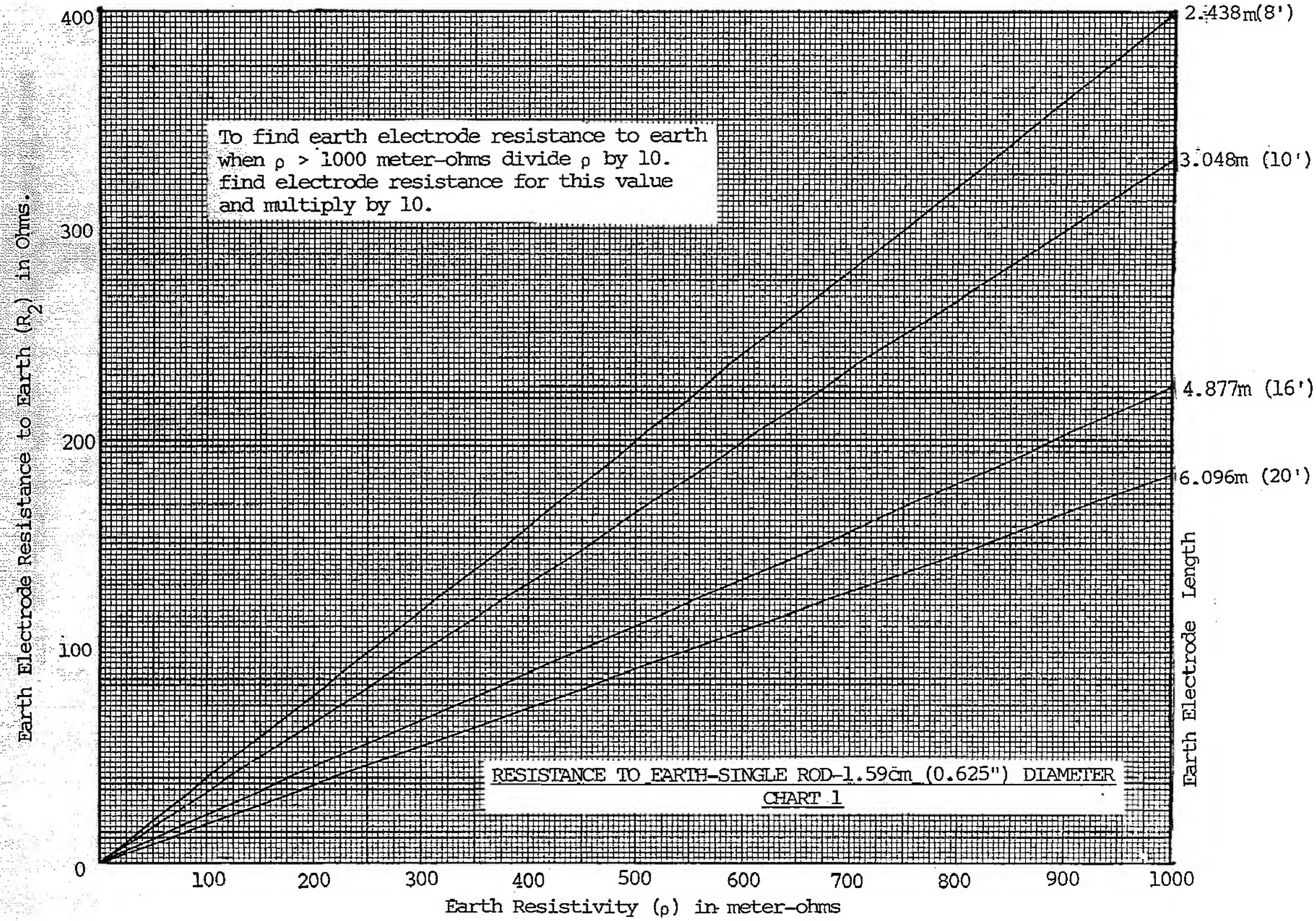
6.34 Following the same procedure equivalent earth resistivities are determined for the six electrode locations with three electrodes from Charts 1 and 3. The resulting 209 meter-ohms is still higher than the 120 meter-ohms objective. The effective resistance to ground from Charts 1 and 6 is 13.0 ohms. Utilization of a fourth rod in parallel would not result in a significant reduction in the effective resistance value.

6.341 The objective earth resistivity of 120 meter-ohms could be met by providing three parallel electrodes 20 feet in length at location 20. This combination would result in an effective resistance to earth at the end of the cable of 9.8 ohms. It is not believed that this design could be economically justified except in areas having very high maintenance costs due to lightning damage.

6.4 Next the average earth resistivity at all points affected by the multiple rods must be recalculated to obtain final values. This starts at the location between electrode 9 and 10 and continues out to the one between electrodes 14 and 15. Finally using Chart 1 to determine the equivalent 3.048 meter (10 foot) electrode resistance for the final average earth resistivity at each location the effective resistance to earth is estimated from Chart 6.

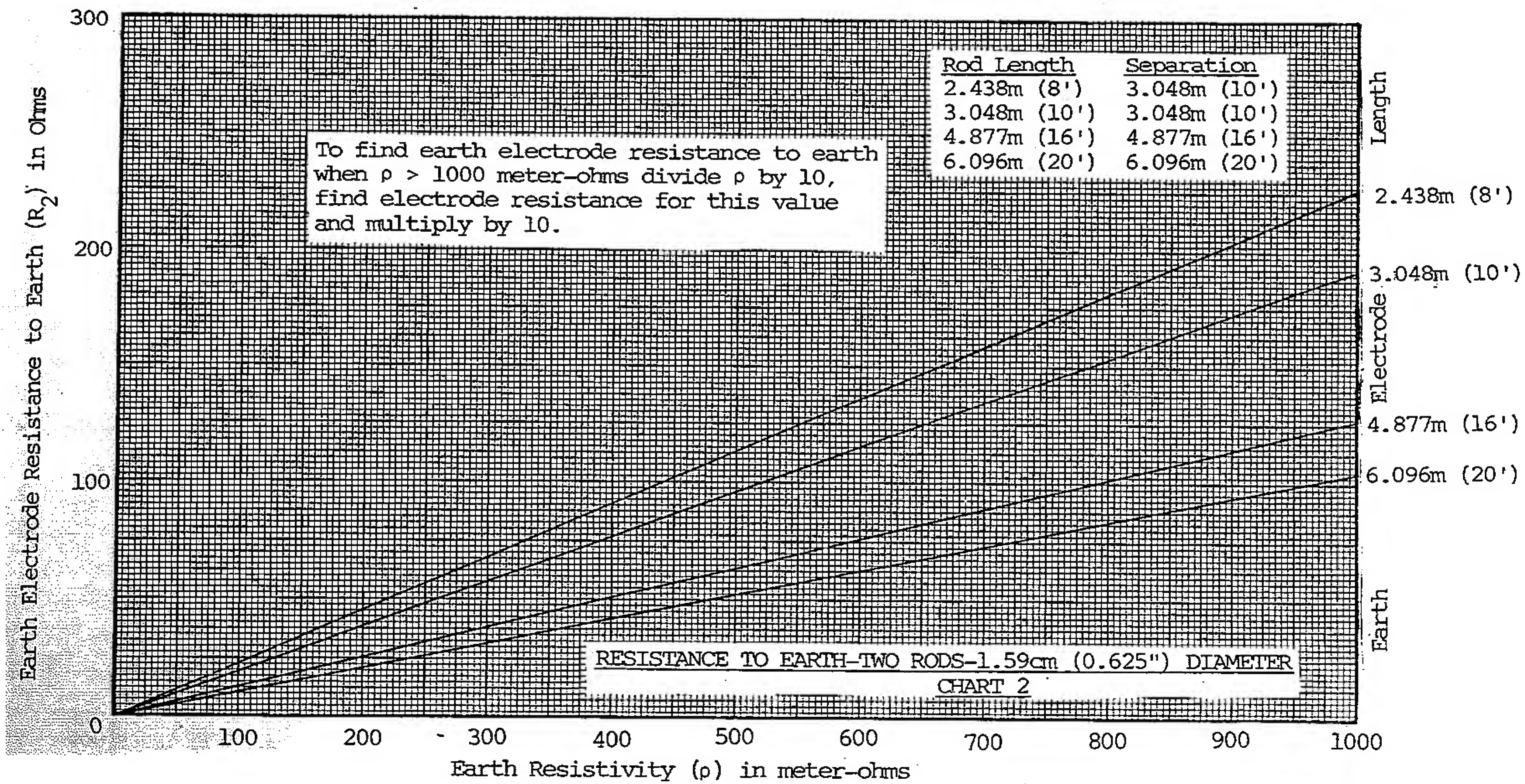
6.5 Design along the branch cable is completed in exactly the same manner starting at the location between electrodes 12 and 13a.

6.6 As stated previously with the low resistance electrode at the office there is no need to study this end of the cable in detail.

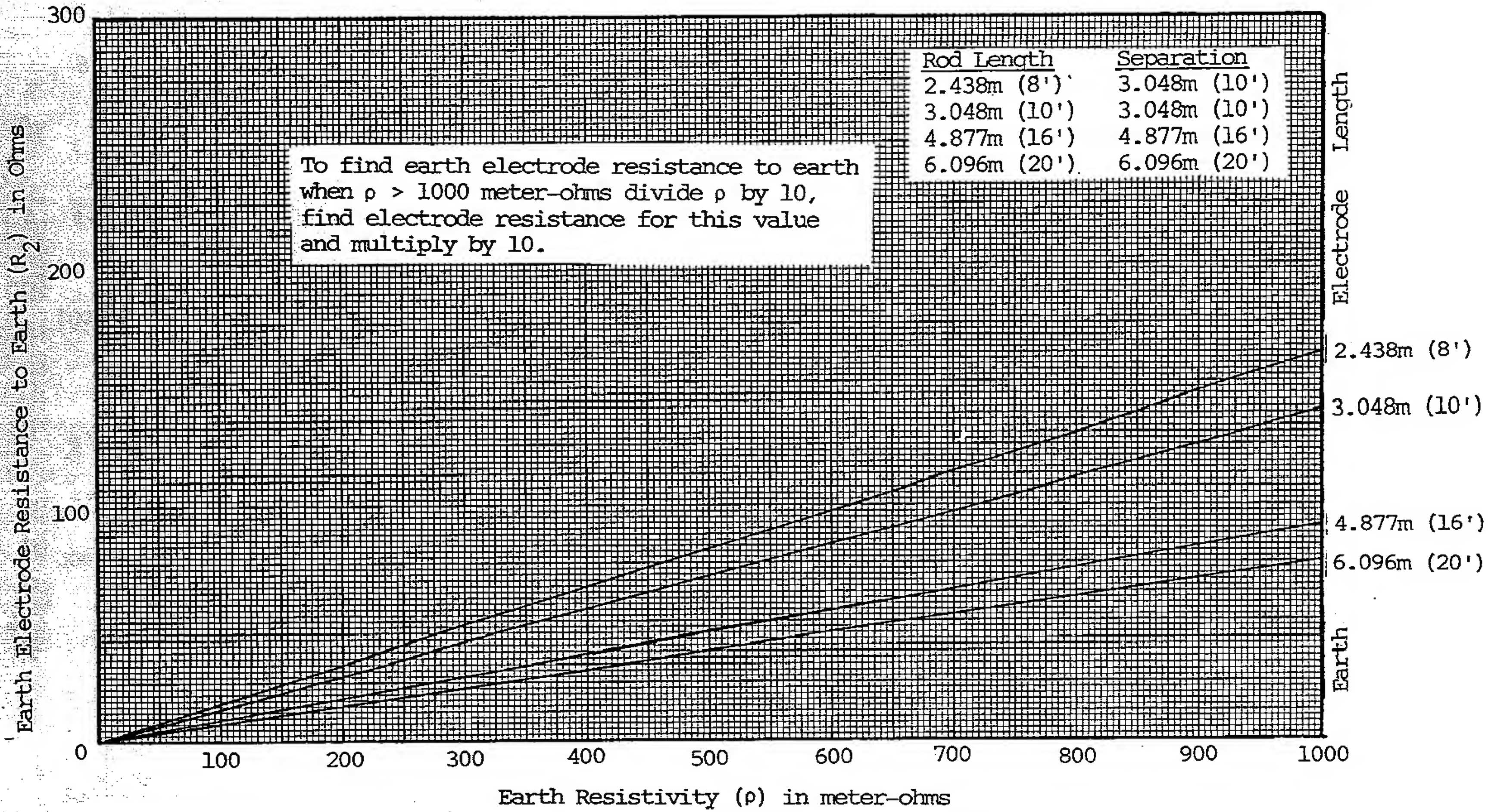



RESISTANCE TO EARTH-SINGLE ROD-1.59cm (0.625") DIAMETER

CHART 1

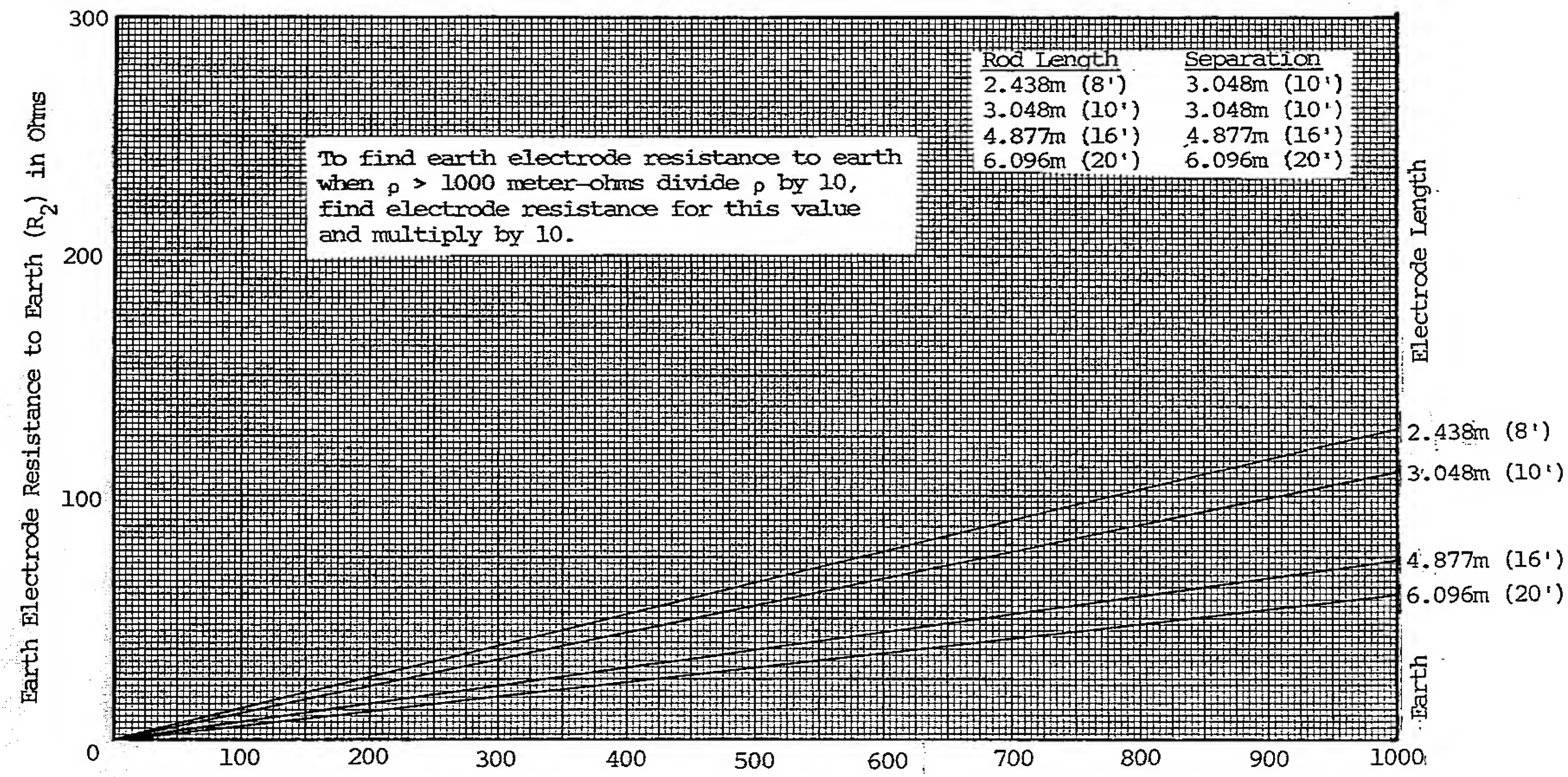



RESISTANCE TO EARTH–TWO RODS–1.59cm (0.625") DIAMETER
CHART 2




RESISTANCE TO EARTH–THREE RODS–1.59cm (0.625") DIAMETER

CHART 3




<u>RESISTANCE TO EARTH–FOUR RODS–1.59cm (0.625") DIAMETER</u>

<u>CHART 4</u>

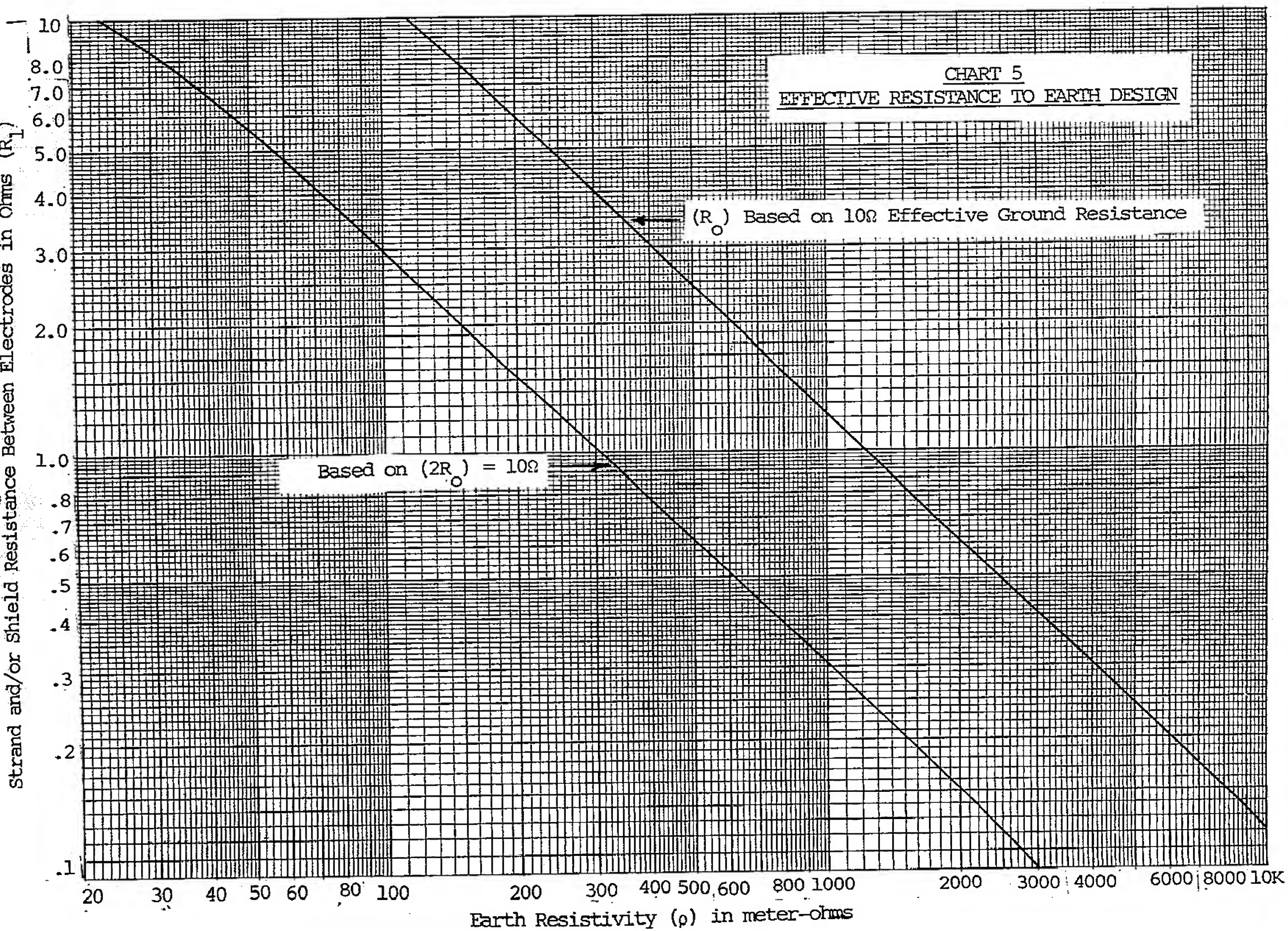
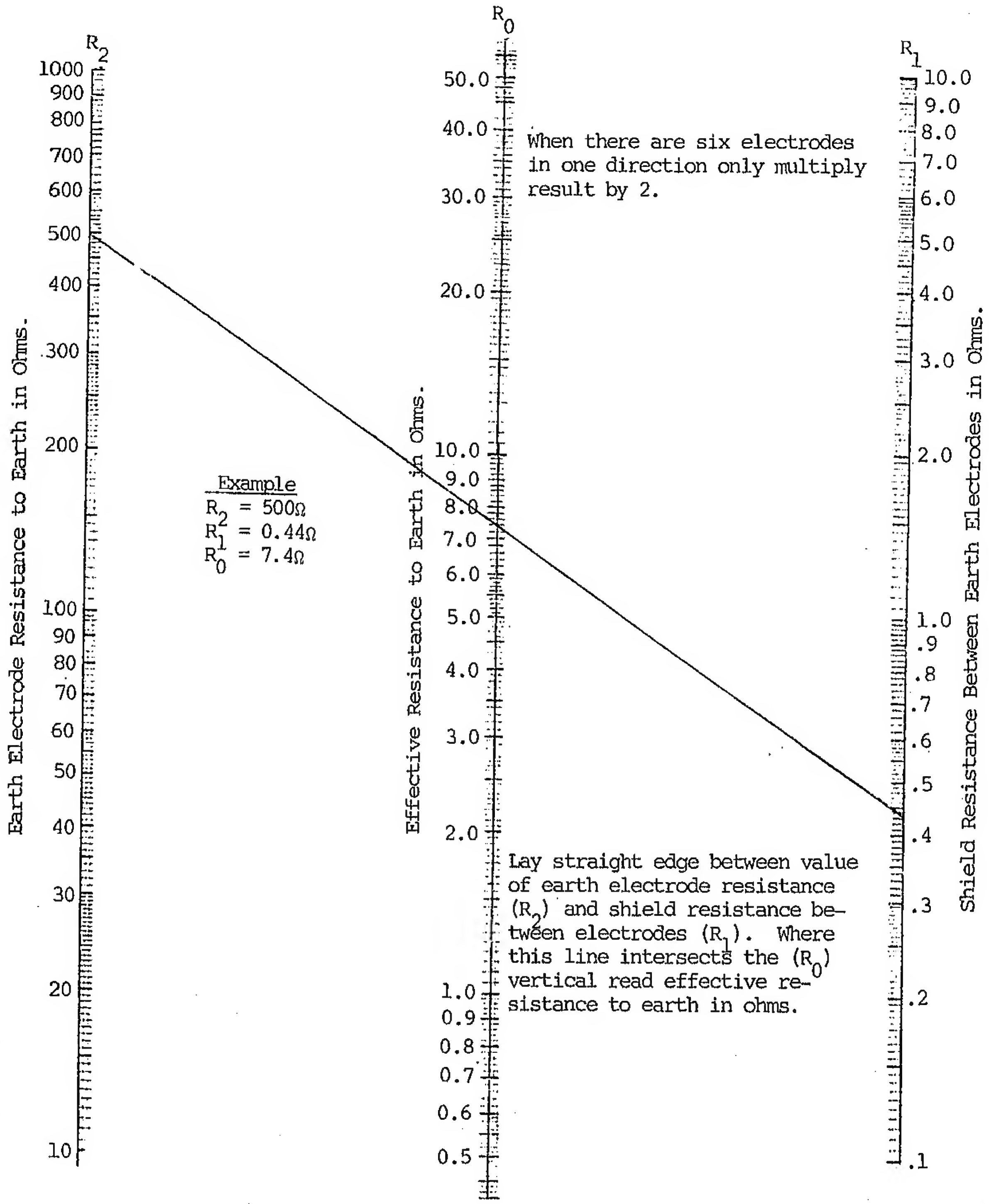
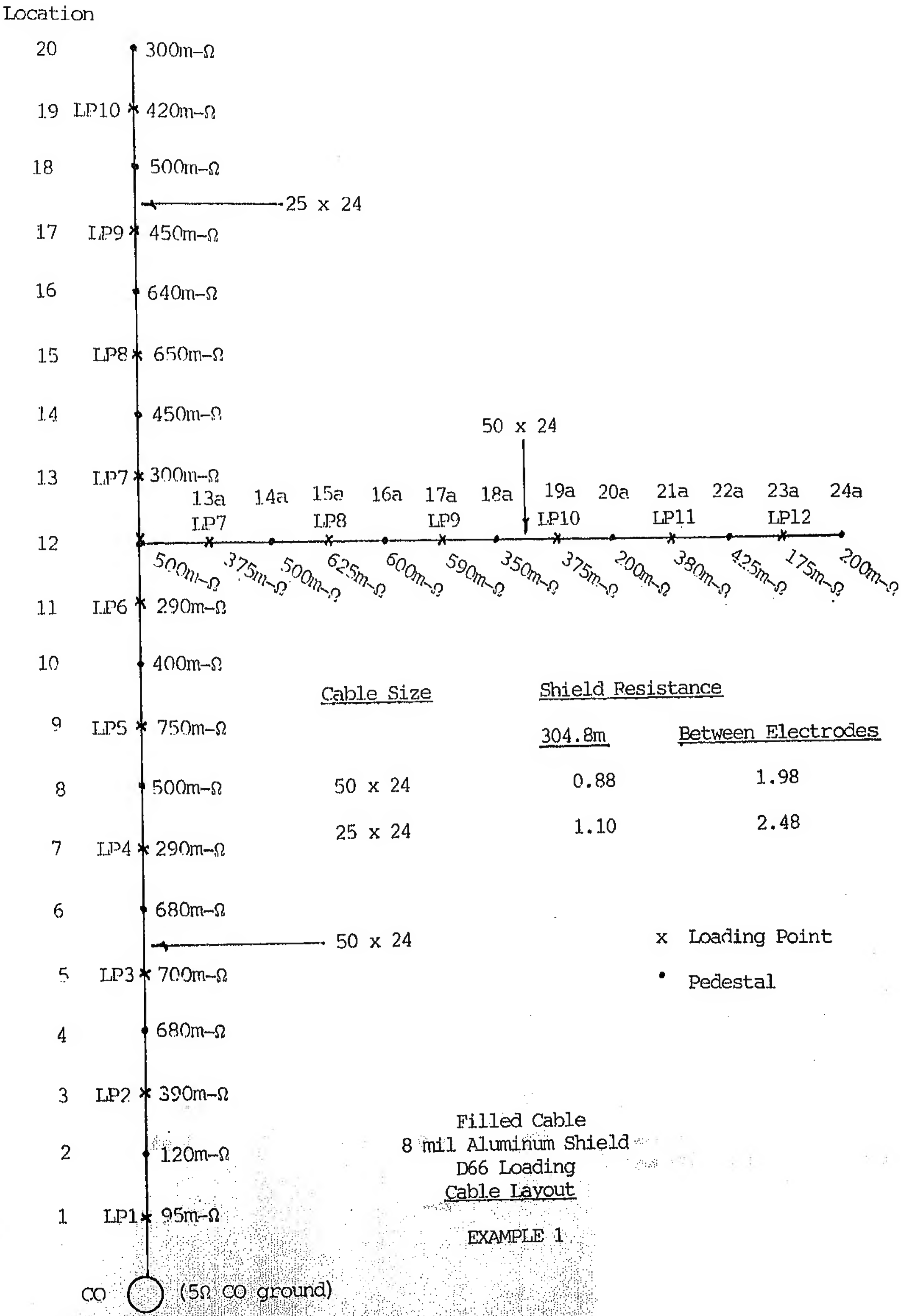


CHART 5
EFFECTIVE RESISTANCE TO EARTH DESIGN
($R_o$) Based on 10Ω Effective Ground Resistance
Based on ($2R_o$) = 10Ω
Strand and/or Shield Resistance Between Electrodes in Ohms ($R_1$)
10
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.8
.7
.6
.5
.4
.3
.2
.1
20
30
40
50
60
80
100
200
300
400
500
600
800
1000
2000
3000
4000
6000
8000
10K
Earth Resistivity (ρ) in meter-ohms




Nomograph for Determining Effective Resistance to Earth in Ohms.
CHART 6




| Cable Size | Shield Resistance 304.8m | Between Electrodes |
|---|---|---|
| 50 x 24 | 0.88 | 1.98 |
| 25 x 24 | 1.10 | 2.48 |

Filled Cable
8 mil Aluminum Shield
D66 Loading
Cable Layout

EXAMPLE 1

WORK SHEET - EXAMPLE 1

| Location | Measured 3.048M | Measured 6.096M | Earth Equivalent | Resistivity Objective | Average First | Average Second | Third | Average Shield R. | Calculated Effective R |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 95 | | | | | | | | |
| 2 | 120 | | | | | | | | |
| 3 | 390 | | | | | | | | |
| 4 | 680 | 680 | | | | | | | |
| 5 | 700 | 700 | | | | | | | |
| 6 | 680 | 680 | | | | | | | |
| 7 | 290 | | | 605 | 450 | | | 1.98 | 8.6 |
| 8 | 500 | | | 600 | 467 | | | 2.02 | 8.9 |
| 9 | 750 | 750 | | 590 | 494 | | | 2.06 | 9.2 |
| 10 | 400 | | | 580 | 516 | 485 | | 2.11 | 9.2 |
| 11 | 290 | | | 560 | 513 | 451 | | 2.15 | 9.0 |
| 12 | 500 | | | 550 | 508 | 408 | | 2.19 | 8.6 |
| 13 | 300 | | | 540 | 477 | 369 | | 2.23 | 8.3 |
| 14 | 450 | | | 530 | 488 | 360 | | 2.27 | 8.2 |
| 15 | 650 | 650 | (3) 275<br>(2) ~~380~~ | 520 | 471 | 329 | | 2.31 | ~~9.5~~ 7.[illegible] |
| 16 | 640 | 640 | (3) 272<br>(2) ~~370~~ | | | | | | |
| 17 | 450 | 450 | (3) 190<br>(2) ~~265~~ | | | | | | |
| 18 | 500 | 500 | (3) 210<br>(2) ~~295~~ | | | | | | |
| 19 | 420 | 420 | (3) 180<br>(2) ~~245~~ | | | | | | |
| 20 | 300 | 300 | (3) 125<br>(2) ~~175~~ | 120 | 493 | 288 | 209 | 2.48 | (2) ~~15.4~~<br>(3) 13.0 |
| 13a | 375 | | | 605 | 481 | | | 1.98 | 8.9 |
| 14a | 500 | | | 605 | 488 | 450 | | 1.98 | 8.6 |
| 15a | 625 | | | 605 | 463 | 443 | | 1.98 | 8.5 |
| 16a | 600 | | | 605 | 432 | 399 | | 1.98 | 8.1 |
| 17a | 590 | | | 605 | 434 | 386 | | 1.98 | 7.9 |
| 18a | 350 | | | 605 | 425 | 371 | | 1.98 | 7.8 |
| 19a | 375 | 375 | (3) 160<br>(2) ~~219~~ | 605 | 400 | 339 | | 1.98 | 7.5 |

WORK SHEET - EXAMPLE 1 (Continued)

| Location | Measured 3.048M | Measured 6.096M | Earth Equivalent | Resistivity Objective | Average First | Average Second | Third | Average Shield R | Calculated Effective R |
|---|---|---|---|---|---|---|---|---|---|
| 20a | 200 | 200 | (2) 115 | | | | | | |
| 21a | 380 | 380 | (2) 222 | | | | | | |
| 22a | 425 | 425 | (3) 170<br>(2) ~~250~~ | | | | | | |
| 23a | 175 | 175 | (2) 103 | | | | | | |
| 24a | 200 | 200 | (2) 115 | 150 | 293 | 170 | 148 | .98 | ~~10.6~~ 9.9 |